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Method for etching openings with a controlled wall profile.

The method comprises providing a mask layer - (14) upon said layer (10) having a mask opening - (16) of the desired bottom-most dimension of said opening (18) to be etched; placing said mask covered layer (10) within an etching reactor with a short species residence time; and performing a reactive ion etching process in said reactor, said process including changing the etching species at appropriate times during the etching of said opening (18) in said layer (10).

Preferably the layer (10) comprises an insulating material and the desired wall profile is advised by changing the percentage gas concentration of a reactive species at least at one predetermined point during the etching process.

With the method the wall profile of said etched opening (18) can be controlled precisely.

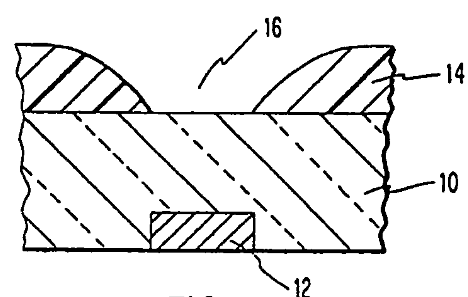

FIG. 4A

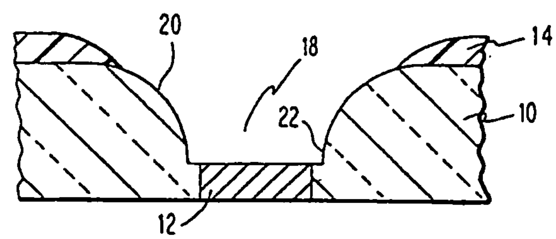

FIG. 4B

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METHOD FOR ETCHING OPENINGS WITH A CONTROLLED WALL PROFILE

The invetion relates to a method for etching openings with a controlled wall profile in a layer of material.

In the fabrication of semiconductor integrated circuit devices vias or openings are formed in an insulating layer prior to metallization to provide contacts to underlying regions. It is preferable that these openings have a rounded profile in order to minimize the possibility of defects in the overlying metal layer. One problem is a step-coverage defect, which sometimes occurs when a metal layer is formed over an opening having a steep profile and causes a discontinuity in the conductor formed by the metal layer. Such steep openings, that is, openings having nearly vertical sidewalls, typically occur when an insulating layer is anisotropically etched, for example by a plasma or reactive ion etching process.

The insulating layer via profile becomes more important as the number of metal interconnection layers increases and the thickness of each metal layer decreases

One method for providing an opening having a sloped profile is to form a predetermined slope in the sidewalls of the openings in a mask layer overlying the insulating layer to be etched. The sidewall profile in the mask layer, typically a photoresist, is then transferred to the opening in the insulating layer during the etching process. A disadvantage is that this method requires an extra high temperature bake step to form the desired opening profile in the mask layer. This step to obtain a predetermined slope in the mask layer is not easily controlled, thus resulting in an etch profile that is difficult to repeat from wafer to wafer.

Another method of providing a sloped sidewall profile during anisotropic plasma or reactive ion etching is to vary the ion bombardment energy. However, this requires a complex triode or a flexible diode reactor and it is often difficult to precisely control the profile.

The prior art teaches various methods of tailoring the reactive etchant species used in plasma etching to achieve a particular etch rate and selectively relative to the layer being etched, the underlying layer and the photoresist mask layer. For example, U.S. Patent No. 4,174,251 to Paschke describes a two step etching process for a low pressure plasma reactor wherein a silicon nitride layer is etched through a hydrocarbon photoresist mask without destroying the mask layer. The process includes a pre-etch step using a high plasma power level and a 95:5 CF_4:O_2 etchant gas to etch halfway through the silicon nitride layer, followed by a main etch step at a lower power level, using a 50:50 CF_4O_2 etchant gas to etch the remainder of the silicon nitride layer.

U.S. Patent No. 3,940,506 to Heinecke discloses a method of adjusting the concentration of a reducing species, such a hydrogen, in a plasma to control the relative etch rates of silicon and silicon dioxides or silicon nitride, particularly for use in a low pressure plasma reactor. Hydrogen is used to control the selectivity and may be added to the CF_4 etchant gas mixture by using a partially fluorine substituted hydrocarbon such as CHF_3.

U.S. Patent No. 4,324,611 to Vogel et al. describes a method for tailoring a reagent gas mixture to achieve a high etch rate, high selectivity and low breakdown of photoresist in a single wafer, high power, high pressure reactor. The disclosed reagent gas mixture includes a primary etching gas consisting of a pure carbon-fluorine, and a secondary gas containing hydrogen to control the selectivity of the etch. A tertiary gas containing helium may be included to prevent the breakdown of the photoresist mask layer. In one embodiment for plasma etching silicon dioxide or silicon nitride overlying silicon, the primary gas is C_2F_6 and the secondary gas is CHF_3.

It is therefore an object of the present invention to provide a method for controlling the profile of an etched opening in layer of material.

Another object of the invention is to provide a method for plasma etching an insulating layer to provide an opening having a desired profile.

Preferably the wall profile of opening is controlled during plasma etching by changing the percentage gas concentration of the etching species at least at one predetermined point during the etching process.

Advantageously the layer to be etched comprises an insulating material, like silicon dioxide, and said mask layer comprises a photoresist, like a hydrocarbon photoresist.

For forming an opening in a silicon dioxide layer having a shallow sloped sidewall in its upper portion and a steep sloped sidewall in its lower portion, the silicon oxide layer is etched through a hydrocarbon photoresist mask layer where at the beginning of the etching a high initial percentage gas concentration of CHF_3 is selected to achieve a high silicon dioxide:photoresist etch rate ratio and after etching through a portion of the silicon dioxide layer, the percentage gas concentration of the CHF_3 is decreased to decrease the silicon dioxide:photoresist etch rate ratio.

Other advantageous embodiments of the inventive method are disclosed in the subclaims.

The inventive method will become more apparent from the following detailed description taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a graphical representation of the insulating layer/photoresist etch rate ratio as a function of the percentage gas concentration of CHF_3 according to the method of the present invention;

Fig. 2 is a graphical representation of the respective etch rates of the insulating and photoresist layers as a function of the percentage gas concentration of CHF_3;

Fig. 3 is a graphical representation of the resulting slope angle of the etched opening, with respect to the horizontal, as a function of the insulating layer/photoresist etch rate ratio;

Fig. 4A is a cross-sectional view of a portion of a masked insulating layer prior to etching; and

Fig. 4B is a cross-sectional view of the masked insulating layer of Fig. 4A after the etching process according to the present invention is conpleted.

It has been found, in the reactive etching of an insulating layer such as silicon dioxide that when pure CF_4 gas is employed as the reactive species there is no undercutting of a hydrocarbon (HC) photoresist. Also, the etch rate ratio of silicon dioxide to HC photoresist is approximately 0.97:1. Further, when a secondary gas such as CHF_3 is added to the CF_4 the etch rate ratio increases, as shown in Fig. 1. The actual etch rates of silicon dioxide and the HC photoresist are plotted in Fig. 2 as a function of the gas concentration in CHF_3, expressed as a percentage of the CHF_3 + CF_4 mixture. As shown, the etch rate of silicon dioxide varies over a relatively small range while the etch rate of the HC photoresist substantially decreases as CHF_3 is added to the etchant gas mixture.

As the silicon dioxide:photoresist (SiO_2:HC) etch rate ratio is varied, as shown in Fig. 3, the sidewall slope angle of the final etched opening in the silicon dioxide layer also varies. Thus, a low SiO_2:HC etch rate ratio results in a small sidewall slope angle with respect to the horizontal, i.e., a shallow etched opening profile, whereas a high etch rate ratio results in a large sidewall slope angle or a steep etched opening profile.

Referring now to Figs. 4A and 4B, the relationship between the percentage CHF_3 concentration in the etchant gas and the slope angle of the etched opening sidewall is used to control the opening profile. Figure 4A shows a portion of an insulating layer 10, for example, silicon dioxide which may be formed on a silicon body (not shown) or other underlying layer. Included in layer 10, for purposes of illustration, is a conductor 12 which may be a portion of a metallic interconnection layer. Overlying layer 10 is a mask layer 14, for example, a hydrocarbon photoresist, including mask openings 16 through which layer 10 will be etched. Mask opening 16 can be formed by any of a number of well known processes.

Fig 4B shows layer 10 after the completion of the present etching process wherein an opening 18 has been formed. The upper sidewall portion 20 of opening 18 is formed by using an etchant having a high percentage CHF_3 gas concentration during the initial phase of the etching process. Referring again to Figs. 1 and 3, the etchant has a high etch rate ratio of SiO_2:HC and therefore causes sidewall portion 20 to initally have a high slope angle with respect to the horizontal. In other words, a smaller thickness of the photoresist layer 14 is etched as compared to the thickness of the SiO_2 layer 10 etched during the initial etching phase.

After a portion, for example, one-half, of layer 10 has been etched the percentage CHF_3 gas concentration is decreased. The etch rate ratio is similarly decreased resulting in a high final slope angle for the lower sidewall portion 22 of opening 18 as compared to upper portion 20. That is, since a greater thickness of photoresist layer 14 is etched than during the initial etching phase, a larger surface area of SiO_2 layer 10 will be uncovered during the final etching phase, causing the upper portion 20 of layer 10 to have a shallower final etched slope than the lower portion 22. In the example shown in Fig. 4B, the etching process is completed when the upper surface of conductor 12 is fully exposed.

It will be apparent to those skilled in the art that other reactive species may be used in the present process in place of CHF_3, for example,C_2F_6 or C_3F_8.

As an illustrative example of the present process, a silicon wafer having a 2.0 µm SiO_2 layer thereon was etched through a 2000 nm diameter opening in a photoresist layer approximately 1500 nm thick. The process was carried out in a single wafer, planar plasma reactor at an RF frequency of

about 13.56 MHz., an RF power of about 200 watts and a pressure of about 1.33 mbar. The initial CHF_3 gas concentration was about 5%. resulting in an upper sidewall slope of about 30 degrees. The final CHF_3 gas concentration was about 25% and the final lower sidewall slope was about 85 degrees. The entire etching process took approximately two minutes. This process is particularly adaptable to single wafer, high pressure plasma reactors having a relatively small plasma chamber volume, for example, less than about 40 cc. The small chamber volume results in a low residence time and permits the precise control of the opening profile, since a change in CHF_3 concentration causes an extremely fast change in the etch rate ratio. Under the above-described process conditions this change has been observed to occur in less than 0.5 seconds.

Since the etchant gas concentration is changed abruptly during the etch cycle, a slight discontinuity in the etched profile is observed. Although this will not affect step coverage during subsequent metal deposition, the discontinuity can be avoided and the smoothly varying profile as shown in FIG. 4B can be achieved by continuously varying the CHF_3 concentration. This can readily by carried out by using, for example, a microprocessor or an analog control loop.

There has thus been provided by the present invention a reactive plasma etching process wherein the profile of an opening formed in an insulating layer may be precisely controlled, regardless of the original slope in the mask layer.

Claims

1. A method for etching an opening (18) having a desired profile through a layer (10), comprising:

providing a mask layer (14) upon said layer (10) having a mask opening (16) of the desired bottom-most dimension of said opening (18) to be etched;

placing said mask covered layer (10) within an etching reactor with a short species residence time; and

performing a reactive ion etching process in said reactor, said process including changing the etching species at appropriate times duringf the etching of said opening (18) in said layer (10) to control the profile thereof.

2. Method according to claim 1 wherein said etching species is changed by changing its percentage gas concentration at least at one predetermined point during the etching process.

3. Method according to claim 1 or 2 wherein said etched layer (10) comprises an insulating material, like silicon dioxide, and said mask layer (14) comprises a photoresist, like a hydrocarbon photoresist.

4. Method according to claim 2 or 3 wherein the etching species contains a gas selected from the group CHF_3, C_2F_6 and C_3F_8.

5. Method according to any one of claims 1 to 4 wherein said etching species comprises CHF_3 and CF_4.

6. Method according to any one of claims 2 to 5 wherein said silicon dioxide layer (10) is reactively ion etched using a high percentage CHF_3 gas concentration in said reactor during the etching of a first portion of said layer (10) and then decreasing the percentage CHF_3 gas concentration in said reactor during the etching of a second portion of said layer (10).

7. Method according to claim 6 wherein the initial percentage CHF_3 gas concentration is at least about 25%.

8. Method according to claim 6 or 7 wherein the final percentage CHF_3 gas concentration is between about 5% and 25%.

9. Method according to any one of claims 1 to 8 wherein the pressure in said reactor is on the order of 1.33 mbar.

10. Method according to any one of claims 1 to 9 wherein said etching species is changed continuously during the etching of said opening (18).

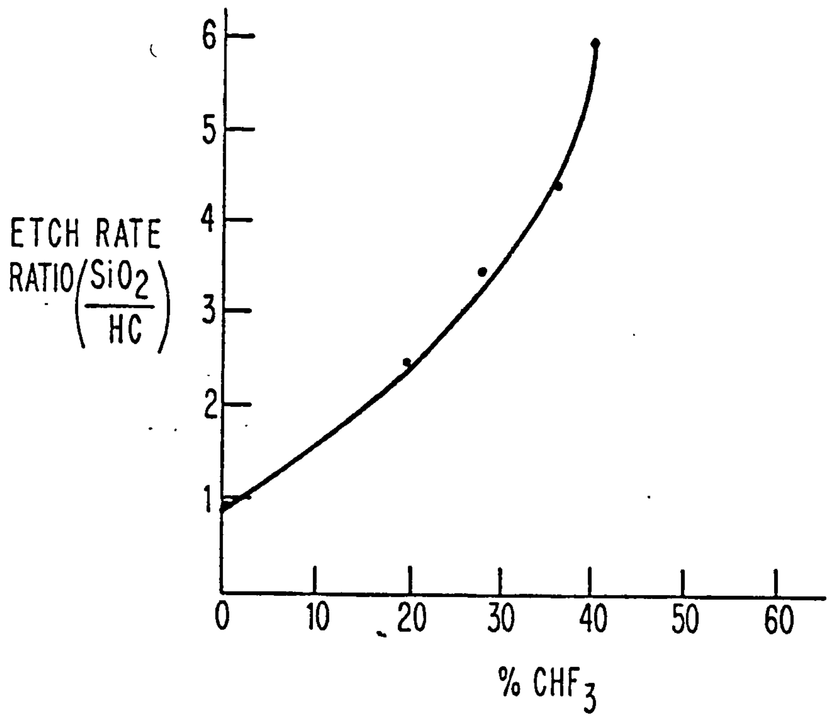
ETCH RATE
RATIO (SiO2 / HC)
6
5
4
3
2
1
0
10
20
30
40
50
60
% CHF3

FIG. 1

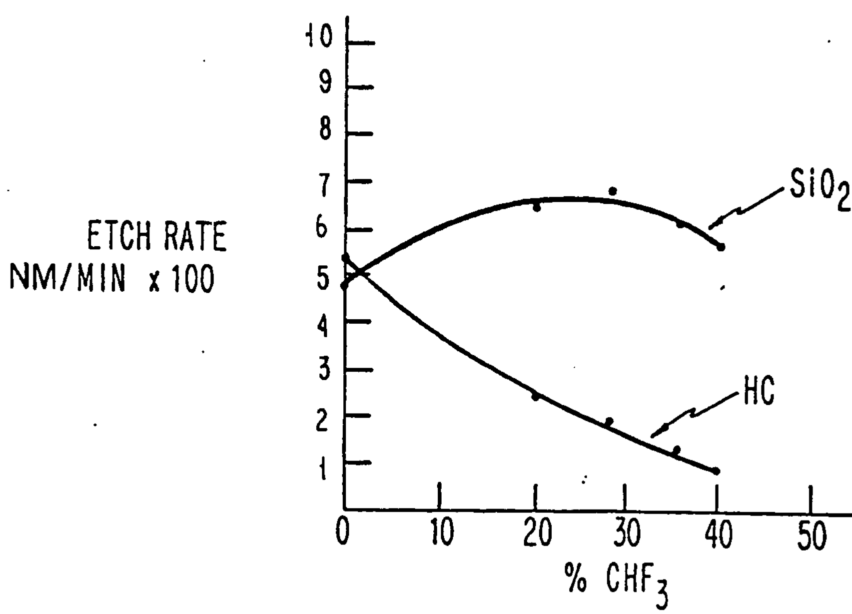
ETCH RATE
NM/MIN x 100
10
9
8
7
6
5
4
3
2
1
SiO2
HC
0
10
20
30
40
50
% CHF3

FIG. 2

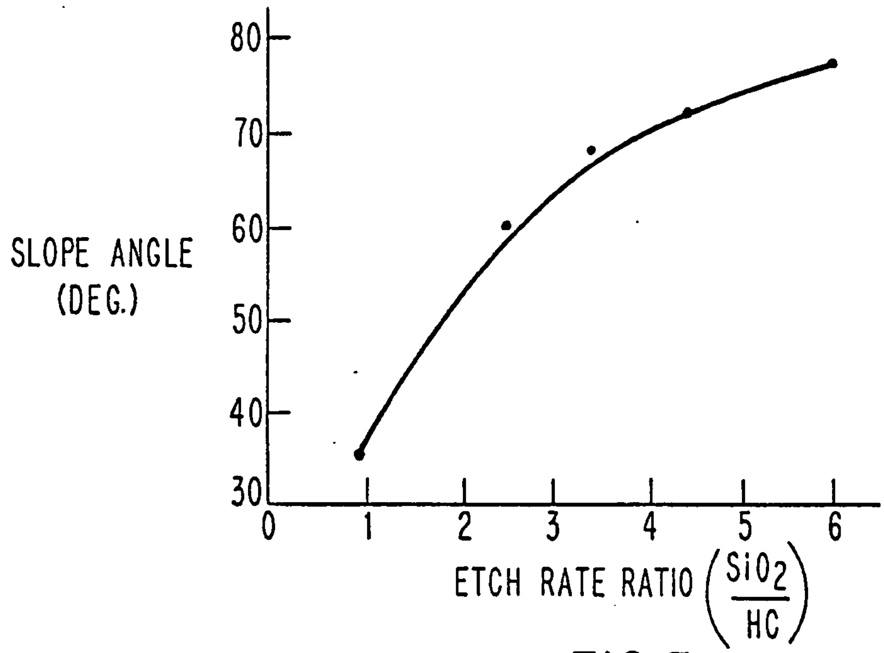

FIG. 3

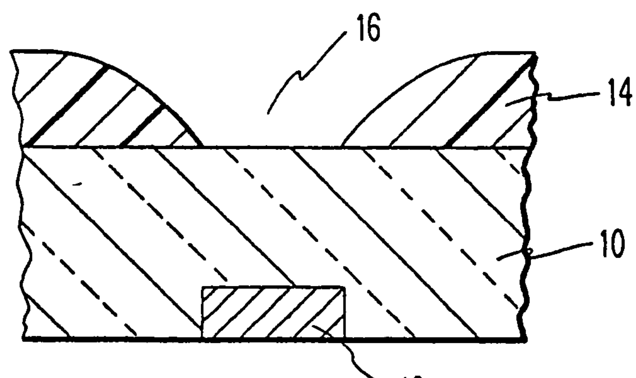

FIG. 4A

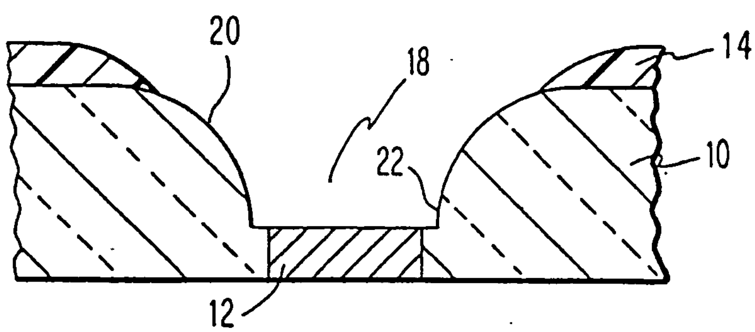

FIG. 4B